A PROCESS FOR WATERFLOOD PERFORMANCE MONITORING

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Executive Summary

This paper presents a methodology for evaluating waterflood performance on a pattern-by-pattern basis to identify wells that may benefit from some type of intervention or remediation. We developed this approach to have a rapid screening method to analyze the commonly available data from a waterflood and maximize the amount of useful information that can be determined from these data. We calculate permeability and the variation in skin factor at the injector with time. We also calculate average reservoir pressure, saturation and net voidage within each pattern as a function of time. Diagnostic plots and maps show regions of high and low reservoir pressure, areas of poor sweep efficiency and the locations and types of various conformance problems.

We have implemented the technique described here in a spreadsheet program on a PC. We also use a mapping software package to visualize and present the results of the analysis. We show how to calculate skin factor at injection wells and average reservoir pressure as a function of time on a pattern-by-pattern basis. We also describe several diagnostic plots and maps to visualize and evaluate the waterflood performance. The data required for this analysis consists primarily of data that is gathered during the normal course of waterflood operations. We use the following data in our analysis.

1. Historical monthly production volumes of oil, water and gas.
2. Historical monthly water injection volumes and pressures for each injection well.
3. Average reservoir pressure and water saturation at the beginning of the analysis (either at the start of primary production or at the beginning of the waterflood).
4. Net pay and porosity distribution, preferably on a pattern-by-pattern basis.
5. The x-y location of each well and, preferably, information on how each well is completed including tubulars, perforations and stimulation.

Introduction

There are many levels of surveillance of waterflood operations. A useful and effective surveillance and evaluation program can be initiated with only production and injection data and an estimate of the volumetric properties of the reservoir. Evaluation of simple waterflood surveillance data can provide the engineer with valuable information that can be used in the management of the project. Spreadsheet and graphic software available on PCs are ideal for developing simple applications for waterflood evaluations.

Discussion

Table 1 is a list of equations used in our waterflood evaluation spreadsheet. As we describe the process workflow we will refer to the equations in this table by number. We will also provide a basic description of how we set up our spreadsheet to perform the calculations. However, there are certainly alternative ways to set up the calculations.

The first step to performing the analysis is to gather the required data. The analysis uses time-based data such as monthly production and injection data. Therefore, the analysis requires a starting point. Average pressure in the pattern is an important variable in many of the reservoir engineering calculations. To perform the calculations, we need a value of pressure at the start of the calculations. If the entire production history for the field is available, then the initial pressure is required. If, however, the entire pre-flood history is not available or the initial pressure is unknown, then the pressure at the start of the waterflood can be used and the calculations performed only over the time period of the waterflood.

Oil, water and gas PVT properties for use in calculations are estimated from correlations since laboratory fluid analyses are rarely available. Equations for correlations can be found in the text by McCain.[1] To use the correlations, information such as oil and gas gravity, water salinity, reservoir temperature, bubble point pressure and initial solution gas-oil ratio must be estimated. These data can be obtained from engineering reports, commission filings or field studies published by geological societies or similar organizations. The age of the field and the number of previous owners will often dictate the amount of available data.

We prefer to put the time-dependent data in a separate file for each well. These files contain monthly columnar data. Since it is not uncommon for production wells to be converted to injectors and vice-versa, all well data files include columns for date (month and year), oil production, gas production, water production, water injection and injection pressure. We like to use comma-delimited files because of their ease of use with spreadsheet programs.

In the spreadsheet, we place a list of injectors and producers. The analysis can be performed on injector-centered patterns or producer-centered. We normally use both approaches, as each will reveal certain things about the behavior of the flood. The tables of wells will include the following.

1. Name of file containing production and injection data for the well.
2. X-y location of the well.
3. Average porosity, water saturation and net thickness for the pattern containing the well. Initial pressure, if available for each pattern, can be included here.

Figure 1 is a map showing the locations of injectors and producers in a waterflood. This example is from a line-drive flood and the pattern outlined is for an injector-centered analysis. Note that a pattern in a line drive includes 3 injectors (the center or home injector and its two closest offsets) and 6 producers. If the patterns in a flood are uniform and all the same type, identification of wells in a given pattern can be automated in the spreadsheet. Patterns are named and identified by their center well. Therefore, to identify the member wells of the pattern shown in Fig. 1, we would first calculate the distance from the center injector to all other injectors and producers in the field. Then the two closest injectors and 6 closest producers would be included in the pattern. Also, only the center well is allocated entirely to a given pattern. The edge and corner wells are normally allocated 50% and 25%, respectively, to the pattern. If the patterns are irregular, the pattern members and allocation factors can be entered into the spreadsheet manually. Edge wells can cause problems in the evaluation even when well allocation factors are defined manually. However, as long as the fundamentals of the analysis are understood, the edge phenomenon is not usually a problem.

The next step in the analysis of a pattern is to load the rate and pressure information into the spreadsheet from the individual spreadsheets. We have automated this part of the process with a macro. The macro copies the data from the ".csv" files to the spreadsheet onto a separate page or worksheet. Because wells come on at different times, even after the start of the waterflood, the production data for the wells in the pattern must be aligned for use in the waterflood calculations. We specify a start date for all spreadsheet calculations and use a table lookup function in the spreadsheet to get values for each date in the analysis. However, these table lookup function evaluations are very time consuming in the macro. If all the individual well files are created to begin at the same date, this will allow the spreadsheet to be streamlined significantly.

Once the individual well production and injection data have been loaded and the proper pattern well factors determined, the pattern calculations can be performed. The calculations include the following.

a. The start dates of production and injection for each well in the pattern.
b. The gross and net number of producers and injectors in the pattern as a function of time.
c. The monthly and cumulative oil, water and gas production and water injection for the pattern as allocated to the pattern.
d. The last 12-month average rates and injection pressures.
e. The average rates for the twelve months preceding the start of the waterflood.
f. Monthly reservoir volumes of injection and production for the pattern.
g. The monthly incremental and cumulative net production in reservoir units for the pattern which we term "net-out."

The tabular and graphical output from this tabulation of pattern data is very useful to document and monitor the performance of a waterflood. **Figure 2** shows the oil, gas and water production for a pattern along with the injector and producer well count. The x-axis is in a date format.

In order to improve the performance of a flood, we need some type of quantitative evaluation of the performance. We base our quantitative analysis of injection wells, including estimates of permeability and skin factor, on the Hall Plot.[2] The Hall Plot is based on the equation

$$\sum (p_t - \bar{p} + p_h)\Delta t = \left[\frac{141.2 B_w \mu_w \left[\ln\left({r_e}/{r_w} \right) + s \right]}{k_w h} \right] W_i$$

and is a graphical presentation of the radial flow Darcy Equation integrated with respect to time. The left side of the Hall Plot equation is the pressure difference between the injection wellbore and the average pressure in the pattern. This pressure difference calculated at each time point (monthly) and multiplied by the elapsed time since the start of injection by the center injector. The right side of the Hall Plot equation contains constants in the flow equation (including permeability) multiplied by the cumulative injected water volume. **Figure 3** is a Hall Plot showing typical character. The x-axis is cumulative water injection volume. The y-axis is the Hall Plotting Function, which is the left side of the Hall Plot equation.

Before we can use the Hall plot to estimate permeability and skin factor, we need to know the average reservoir pressure within the pattern area. We use a material balance approach to calculate the pressure changes in the pattern throughout the history of the flood. **Equation 1** gives the cumulative hydrocarbon (oil and gas) production in reservoir units. Thus, this is the reservoir voidage due to production of hydrocarbons. **Equation 2** gives the cumulative water production in reservoir units. **Equation 3** sums the reservoir hydrocarbon and water production volumes to give the total outflow from the reservoir in reservoir units. **Equation 4** is the total reservoir inflow volume in reservoir units assuming the only inflow is water injection and encroachment from an active aquifer. The difference between the total reservoir inflow and total reservoir outflow, **Equation 5**, yields the net reservoir inflow or "net out" from the reservoir. This is the value we need to determine current reservoir pressure within a pattern.

Before we can estimate the average reservoir pressure, we need estimates of oil, gas and water saturations in the pattern. **Equation 6** is an equation for water saturation based on water injection, encroachment and production. Therefore, water saturation is only a function of water inflow and outflow. **Equation 7** is the equation we use to estimate oil saturation. This equation has oil saturation as a function of oil production and water saturation. Finally, gas saturation can be calculated from the equation
$S_g = 1 - S_w - S_o$.

Once all of the saturations are estimated, the total system compressibility is calculated from **Equation 8**. Gas compressibility is dependent on average reservoir pressure. Prior to fillup, the gas compressibility can have a very large effect on the calculated average pressure. In fact, the gas saturation can make interpretation of the Hall Plot very complicated prior to fillup. However, after fillup, gas saturation is very low and this term has a smaller effect on total system compressibility and on the resulting average reservoir pressure. The current average reservoir pressure is calculated from **Equation 9**.

Figure 4 is a pattern material balance plot that shows the reservoir inflow, outflow and net outflow volumes as a function of time. In this example, the graph includes the primary production period. The graph also shows the calculated average reservoir pressure in the pattern. The net outflow curve, labeled "net-out" crosses the zero value on the y-axis when the injection volume equals the cumulative production form the pattern area since the start of production. This plot is very useful in visualizing the progress of the waterflood on a pattern-by-pattern basis. Review of these graphs can show which patterns are not receiving sufficient water injection, which are receiving too much and, when adjacent pattern plots are reviewed together, where migration or channeling of injected water is occurring.

Equation 10 is the Hall Plot equation solved for permeability. Eq. 10 can be significantly effected by gas saturation prior to fillup. We calculate permeability by assuming the skin factor is zero at fillup and using the slope of the line on the Hall Plot to estimate permeability using Eq. 10. For subsequent months after the permeability is calculated, we calculate skin factor from **Equation 11** holding the permeability constant at the value calculated just after fillup. While the absolute values of skin and permeability may not be accurate, we can see how skin factor changes with time and note wells that have a significant increase in skin. We can also inspect these graphs to see the effect of past remediation treatments on the skin factor.

As described previously, we load monthly injection and production volumes for a pattern into columns in our spreadsheet. We then add columns to solve Eqs. 1 through 9 and 11 so we have a calculated skin factor for every month. Eq. 10 is solved separately, once, for permeability. **Figure 5** is a graph of the skin factor for an injection well calculated by our method. In this particular waterflood, the injection pressure in numerous injection wells was allowed to increase above the parting pressure of the reservoir. This appears to be common practice in many Permian Basin waterfloods. As the reservoir is repressurized, however, the parting pressure will also increase. It is normal, therefore, to see the negative calculated skin factors due to fracturing by the injection water. However, around the beginning of 1994, the calculated skin factor saw a significant rise over a two-year period to a value of about 10. A remediation treatment was performed in early 1996 that brought the skin factor down to near the pre-1994 level, indicating a successful remediation.

Waterflood properties can now be determined from equations given in several waterflood textbooks and papers.[3,4,5] Two calculations that are useful for monitoring the performance of a young waterflood are the fillup volume, given in **Equation 12**, and the injection volume required for interference with adjacent injection wells, given by **Equation 13**. Both of these calculations use volumetric parameters that are required in the average pressure calculations. Fillup and interference are usually quite evident on performance plots for a pattern, thus giving two points to compare against the calculated values. Also, these values can be compared to actual values in mature field to help identify producers that may be suffering from conformance problems.

Decline curve analysis can be performed from a plot of oil rate versus cumulative pattern oil as shown in **Figure 6**. This process can be automated to give an estimate of primary and waterflood EUR for large numbers of wells or patterns. As already mentioned, we determine the highest 12 month average rate along with the last 12 month average rate for both the primary production period (prior to the start of injection) and for the waterflood period. **Equation 14** allows for the calculation of the exponential decline rate that agrees with the highest 12-month average rate, the final 12-month average rate and the cumulative oil production. This decline rate is then used in **Equation 15** to determine EUR for the period. While this method of determining EUR is not as accurate as individual decline curve analysis for each well, we have found that it is both useful and efficient in the rapid evaluation of many wells.

In addition to the individual pattern analyses, we create a table containing our analysis of each pattern and the current estimate of skin factor for the center injector for each pattern. We sort the table to identify patterns that have significant remaining reserves and high skin factors as remediation of these wells will have the greatest financial impact on the project. Once we have high-graded the remediation candidates, we use NODAL analysis to verify the amount of skin damage.

Figure 7 is a NODAL analysis for an injection well. The current reservoir pressure, kh and skin factor calculated from the injector-centered spreadsheet was used in this NODAL analysis. The permeability, skin factor and other unknown or uncertain parameters are varied until the computed rate and pressure data match the values from the field data. The NODAL calculated rate is at the intersection of the outflow curve with the inflow curve. The NODAL analysis can also show the injection rate that would result if the skin damage were removed from the well.

Problems with producing wells such as damage (high skin factor) or lifting problems are normally identified by the loss of overall fluid production rate. Often the best way to improve producer performance in a waterflood is to ensure that all of the pay zones that are being flooded are open in the producing well. In most waterfloods we have evaluated in the Permian Basin, the flowing bottomhole pressure in the producing wells is not measured. Most of the wells are on rod pump while a few are producing with the help of electric submersible pumps. The bottomhole pressure can be estimated from these by knowing the flowing tubing pressure and the average liquid level in the wellbore during production. While not commonly performed on a regular basis, shooting fluid levels is a fairly simple job to undertake on a reasonable number of producing wells. We suggest identifying wells that can make the greatest contribution to oil production and then measuring the fluid level on those wells. **Figure 8** is a NODAL analysis for a production well. The current reservoir pressure and kh values that were calculated from the Hall Plot were entered into the NODAL program. Either flowing bottomhole pressure or skin factor can be varied to match the current producing rates. If skin is held constant and an abnormally high fluid level (reflected by a high flowing bottomhole pressure) is necessary to obtain a match, then the well may have a high skin factor. Suspect wells can be tested by obtaining a fluid level. As with the injection wells, the patterns with greater oil reserves can be placed in higher priority for remediation.

A summary worksheet can be created as a one-line summary for each injector centered pattern and one for each producer center pattern. The summary lists each item calculated from the calculation worksheet. This table can then be used with a graphing program to generate plots and maps of each item so that deficiencies in the waterflood can be determined.

Graphical Presentation of Results

Plots and maps of the information obtained by the calculation spreadsheets are the two best ways to see the results of the waterflood. These plots and maps help describe each pattern and allow interpretation and comparison of patterns. Each plot and map will lead to a better understanding of how the injectors and producers are effecting each other and the whole waterflood. Below is a list of plots that the authors have used with some success:

a. Production history
b. Ratio Plot
c. Production decline curves
d. Production diagnostic plots
e. Injection and Production Overlays
f. Material Balance Net-Out Plot
g. Hall Plot
h. Skin Evolution Plot

The production history plot shown previously in Fig. 2 gives an overview of the pattern performance. The plot is a semilog plot with two Y-axis plotted against time on the X-axis. The left Y-axis is the log of oil, water, and gas. The right Y-axis is well count. This plot can help give a general understanding of the pattern's behavior by observing production trends. A decline of all fluid rates may indicate skin or insufficient pattern injections, while a sharp decline may mean pump failure. An increase in water, oil or gas rates may indicate waterflood response as shown in Fig. 2. Also, pattern fill-up may be indicated by a decreasing gas rate. If water rate increases and oil rate decreases, this may indicate a conformance problem.

Production diagnostic plots are the water/oil ratio or gas/oil ratio versus cumulative time on log-log paper. K.S. Chan[6] presents principles for the interpretation of these diagnostic plots. Two important problems regarding waterflooding can be diagnosed with these plots: layer breakthrough and rapid channeling.

Figure 9 shows the typical characteristics seen in the diagnostic plot when layer breakthrough occurs. Layer breakthrough occurs when the reservoir consists of several layers, each one having a different fluid transmissibility. The plot is characterized by five changes in the WOR curve. First, the well is under normal production where the WOR depends on initial water saturation and dual porosity production behavior. Second, the first layer breakthrough is observed and is controlled by well spacing, water front velocity and drawdown rate. Third, the depletion of the layer is observed and is dependent on the permeability and relative permeability of that layer. Fourth, a transition may be observed before another layer breakthrough and fifth, the second layer breakthrough. **Figure 10** shows an example illustrating layer breakthrough behavior.

Figure 11 shows the typical characteristics of the diagnostic plot for a well suffering from rapid channeling. Rapid channeling is characterized by a rapid increase in WOR. A high water conductivity thief layer, a fracture system connecting injector and producer, channeling behind the casing, or a completion failure can cause this increase. **Figure 12** shows an example of rapid channeling.

Figure 13 is an example of a well in a mature waterflood that appears not to be affected by water injection. This could indicate reservoir compartmentalization or channeling of injected water away from this well. This behavior is often seen in the same pattern as rapid channeling since the conductive channel is allowing water to move in one direction but not in another.

Injection and production overlays, as presented in **Figure 14**, give an overview of the effect an injector may have on the producer. Multiple production plots can be made for each producer with different offset injectors included on the plot. This will allow the effect one injector may have on a producer to be determined visually. The plot is a semilog plot with two Y-axis plotted against time on the X-axis. The left Y-axis is the monthly production and injection volumes while the right Y-axis is injection pressure.

As an injector injects water into the pattern this water will fan out radial until it is interfered with by another injector, up until this time the location of the oil bank and water bank can be calculated. The time at which these banks reach the closest producer can also be determined. This information can be included on the injection and production overlay plot. Fig. 14 shows that after the calculated time for the oil bank to reach the producer from the injector being evaluated there is an increase in oil rate. Also, the effects of the communication between the injector and producer can be observed. Note that in the circled area, when injection rate and pressure are decreased production also drops. This plot can be very helpful in finding which injector communicates to which producer.

Figure 15 is an injector-multiple producer overlay plot. This shows the total pattern injection rate and the oil production rate for the producing wells in the pattern. This plot is useful in identifying directional anisotropy and channeling. Note that Producer #4 exhibits a very large response to injection followed by a gentle decline. Producer #1 has a more gradual response to injection, as does Producer #2 after about two years. Producer #3 has little if any response to injection.

Mapping the Results

The mapping of all of the data calculated in the spreadsheet relative to well location is a great way to get an understanding of the overall effect of the waterflood has had on field. Mapping helps move the focus from the wellbore to the field. This change in focus can help determining trouble spots and areas that have the greatest potential. There are several graphing and/or mapping software programs available that can read the information from the summary tables and construct these maps. Below is a list of maps that can be beneficial:

1. Cumulative maps of oil, water, gas, and water injected
2. Rate maps of oil, water, gas, and water injected
3. Reservoir proprieties maps of kh, phi-h, and net height
4. Net-Out map with results from Production diagnostic plots

A cumulative production map can illustrate what the history of production has been in the field. This information combined with other information gained from the spreadsheet, plots, and other maps can show changes in the waterflood. **Figure 16** is a cumulative gas production map that shows where the gas has been produced. **Figure 17** is a gas rate map. Comparing to Fig. 16, notice how the gas production has moved to a new area. This change is a result of movable gas being produced in the up-dip part of the field prior to fill-up.

Reservoir proprieties maps can help identify areas that may need additional work. **Figure 18** is a map of kh. Notice that the kh in the northeastern part of the field is similar to the kh in the heart of the field. **Figure 19** is an oil rate map of the same field. Notice that even though both areas have similar reservoir properties, production is poorer in the northeastern part of the field. A possible reason for this is the difference in well spacing. Therefore, in the northeastern part of the field, an infill drilling program may improve productivity.

The Net-Out map can identify areas in the field where the waterflood is ineffective. **Figure 20** is a Net-Out map with only positive values of Net-Out plotted. Overlaid on this map are the results from the production diagnostic plots that show no response in a pattern (recall Fig. 13). Notice that most of the wells that are showing no response to the flood are located in the section of the field with positive values. That is, reservoir output is greater than water injected. Performance in this area of the field may improve if water injection is increased.

Figure 21 is a Net-Out map with only negative values of Net-Out plotted. Overlaid on this map are the results from the production diagnostic plots that show rapid channeling is a pattern (recall Fig. 12). Notice that most of the wells that are showing rapid channeling are located in the section of the field with negative values. That is water injection is greater than reservoir out put. Therefore in this area of the field water may be injected out of zone.

Specialty maps are all of the other maps that can be generated from the data obtained in the spreadsheets or the plots. **Figure 22** is an example of a map of Oil Cut. This map can be helpful in determining where oil production is most efficient.

Figure 23 is an example of a map of remaining reserves. This map can be used to help determine where the most benefit can be made from future workovers.

Figure 24 is a map of current reservoir pressure. This map can act as a backup to other analysis. Note that in the northeastern part of the map it shows reservoir pressures that are higher than other parts of the field. This agrees with the analysis made previously that an infill drilling program may improve the productivity of this area. Also, observe that in the same area that had a positive Net-Out there also exists the lowest reservoir pressure. Again this agrees with the recommendation to increase the water injection in this area.

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Nomenclature

B_g	=	gas formation volume factor, rb/Mscf
B_o	=	oil formation volume factor, rb/STB
B_{oi}	=	oil formation volume factor at initial pressure, rb/STB
B_w	=	water formation volume factor, rb/STB
c_f	=	formation compressibility, 1/psi
c_g	=	gas compressibility, 1/psi
c_o	=	oil compressibility, 1/psi
c_w	=	water compressibility, 1/psi
d	=	injector spacing, ft
D	=	exponential decline rate, 1/yr
EUR	=	estimated ultimate recovery, STB
Gp	=	cumulative gas production, MSCF
h	=	net pay thickness, ft
k	=	permeability, md
m_{Hall}	=	slope data on Hall Plot, psi-days/STb
N_p	=	cumulative oil production, STB
N_{rp}	=	cumulative oil production, rb
$\overline{p}$	=	average reservoir pressure, psia
p_i	=	initial reservoir pressure, psia
q_a	=	abandonment rate, STB/yr
q_{B12}	=	highest 12-month average rate, STB/yr
q_{f12}	=	final 12-month average rate, STB/yr
r_e	=	effective external flow radius, ½ distance between injectors, ft
r_w	=	wellbore radius, ft
s	=	skin factor, dimensionless
S_g	=	gas saturation, fraction
S_{gi}	=	gas saturation at start of waterflood, fraction
S_o	=	oil saturation, fraction
S_w	=	water saturation, fraction
S_{wi}	=	initial water saturation, fraction
T_{ri}	=	total reservoir inflow, rb
T_{rn}	=	net reservoir outflow, rb
T_{rp}	=	total reservoir outflow, rb
V_p	=	reservoir pore volume, bbl
W_e	=	water influx, rb
W_i	=	cumulative injected water volume, STB
W_{if}	=	cumulative injected water volume at fillup, STB
W_{ii}	=	cumulative injected water volume at interference, STB
W_p	=	cumulative produced water volume, STB
W_{rp}	=	cumulative produced water volume, rb
μ_w	=	water viscosity, cp
ϕ	=	porosity, fraction

Table 1 - Waterflood Evaluation Equations

1	Reservoir Hydrocarbon Production	$N_{rp} = N_p\left[B_o + \left(G_p/N_p - R_s\right)B_g\right]$
2	Reservoir Water Production	$W_{rp} = W_p B_w$
3	Total Reservoir Outflow	$T_{rp} = N_{rp} + W_{rp}$
4	Total Reservoir Inflow	$T_{ri} = W_i B_w + W_e$
5	Net Reservoir Outflow	$T_{rn} = T_{rp} - T_{ri}$
6	Water Saturation	$S_w = \frac{(V_p S_{wi}) + (W_e + W_i - W_p)B_w}{V_p}$
7	Oil Saturation	$S_o = \left(1 - \frac{N_p}{V_p}\right)\left(\frac{B_o}{B_{oi}}\right)(1 - S_w)$
8	Total Compressibility	$c_t = S_o c_o + S_w c_w + S_g c_g + c_f$
9	Average Pressure	$\bar{p} = p_i - \frac{T_{rn}}{V_p c_t}$
10	Permeability from Hall Plot	$k = \frac{141.2 B_w \mu_w \ln\left(r_e/r_w\right)}{m_{Hall} h}$
11	Skin Factor from Hall Plot	$s = \frac{m_{Hall} kh}{141.2 B_w \mu_w} - \ln\left(r_e/r_w\right)$
12	Fillup Volume	$W_{if} = V_p S_{gi}$
13	Injection Volume to Interference	$W_{ii} = \frac{\pi}{2} d^2 \phi h S_{gi}$
14	Average Exponential Decline Rate	$D = \frac{q_{b12} - q_{f12}}{N_p}$
15	Estimated Ultimate Recovery (EUR)	$EUR = N_p + \frac{q_{f12} - q_a}{D}$

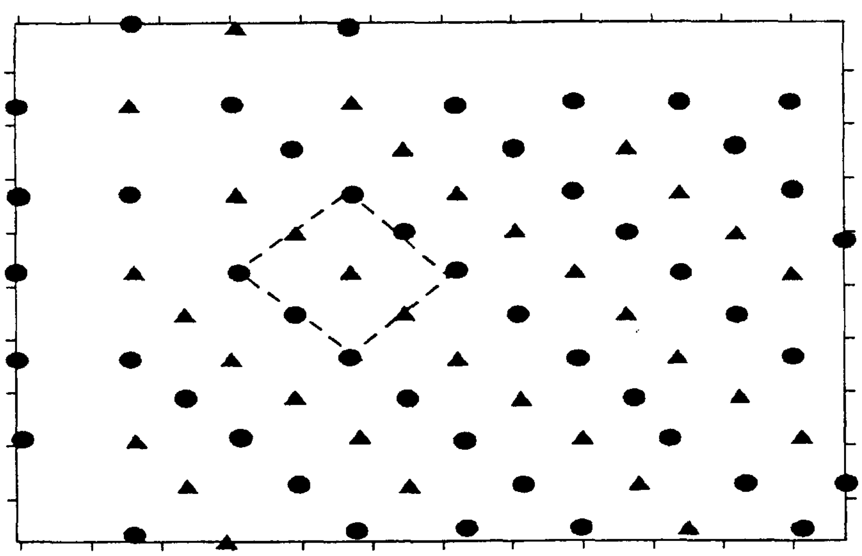

Figure 1 - Location Map with Injector-Centered Pattern

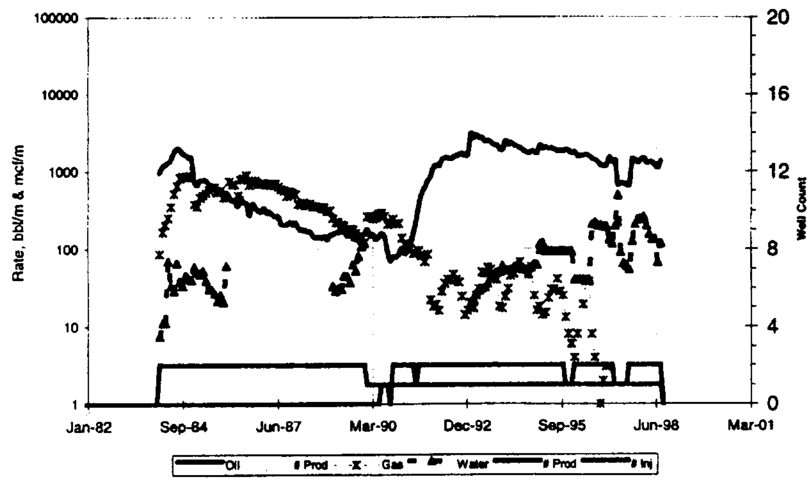

Figure 2 - Historical Production Plot

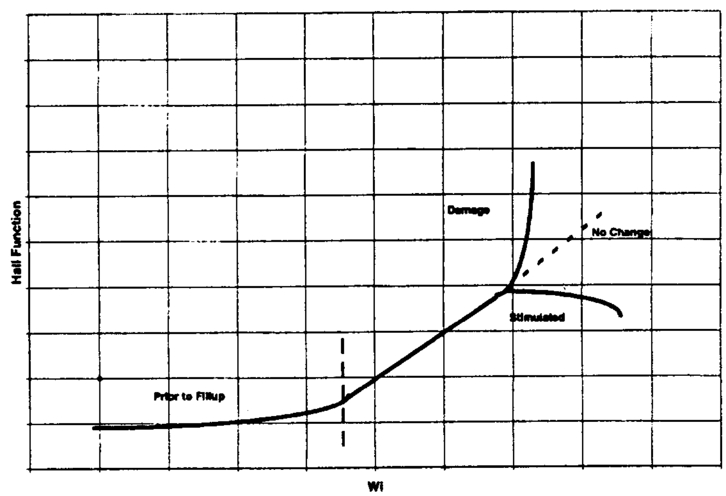

Figure 3 - Hall Plot

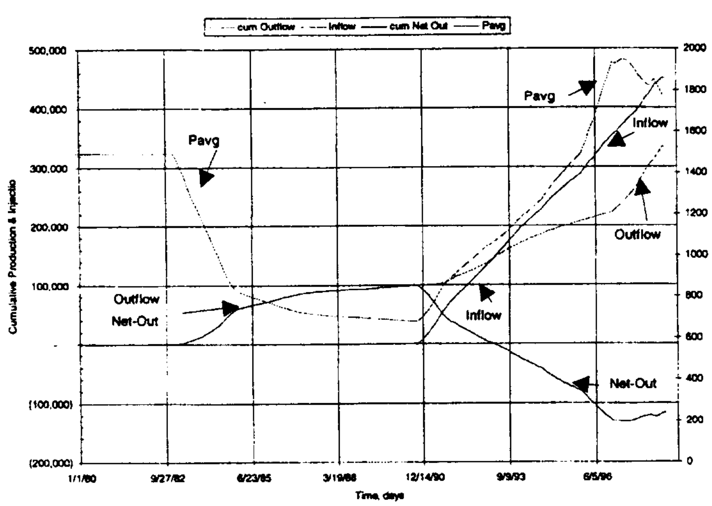

Figure 4 - Material Balance "Net-Out" Plot

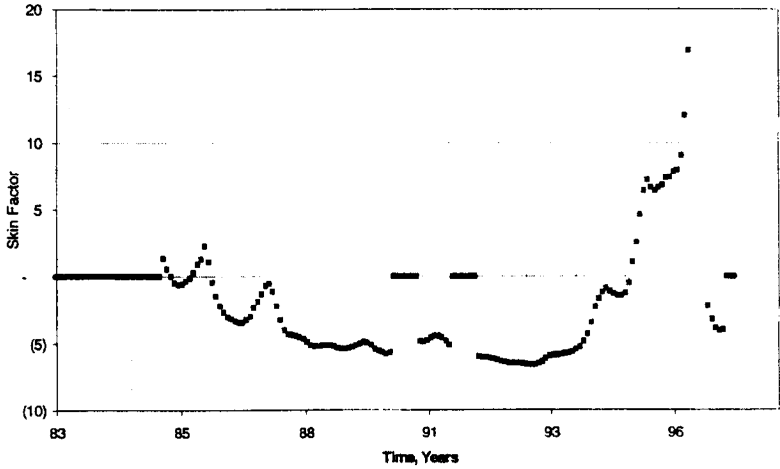

Figure 5 - Skin Evolution Plot

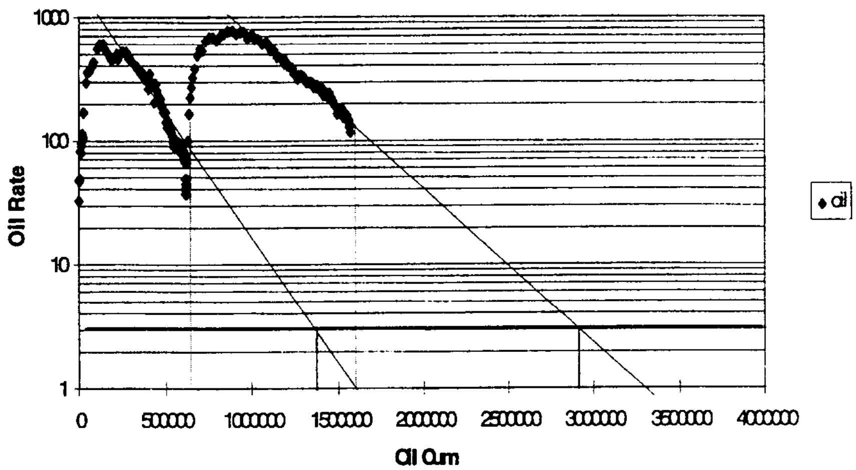

Figure 6 - Rate-Cumulative Decline Plot

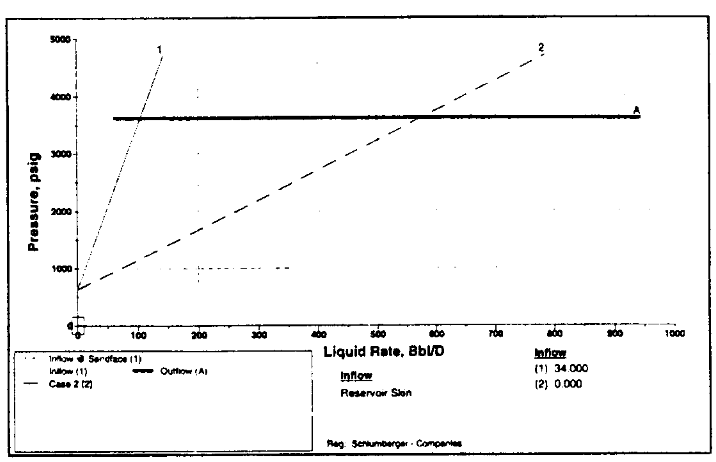

Figure 7 - NODAL Plot of an Injector

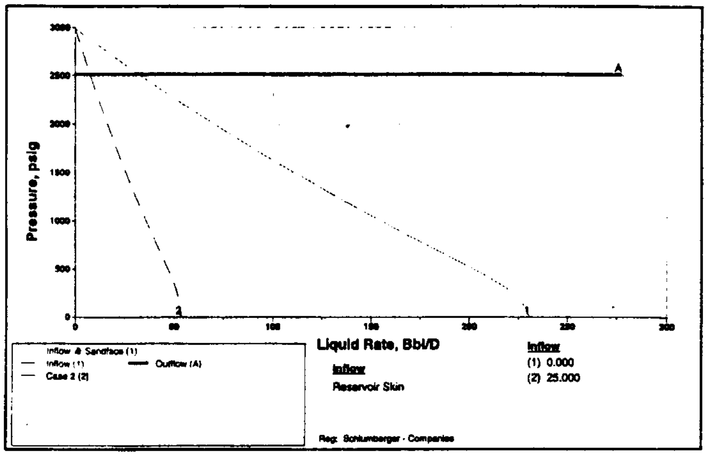

Figure 8 - NODAL Plot of a Producer

LAYER BREAKTHROUGH

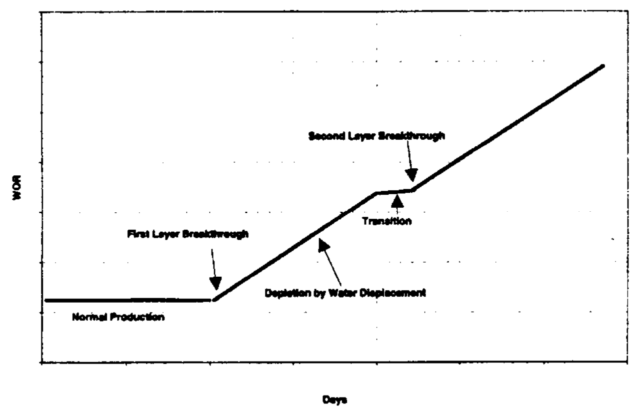

Figure 9 - Layer Break Through Diagnostic Plot Example

WOR Diagnostics

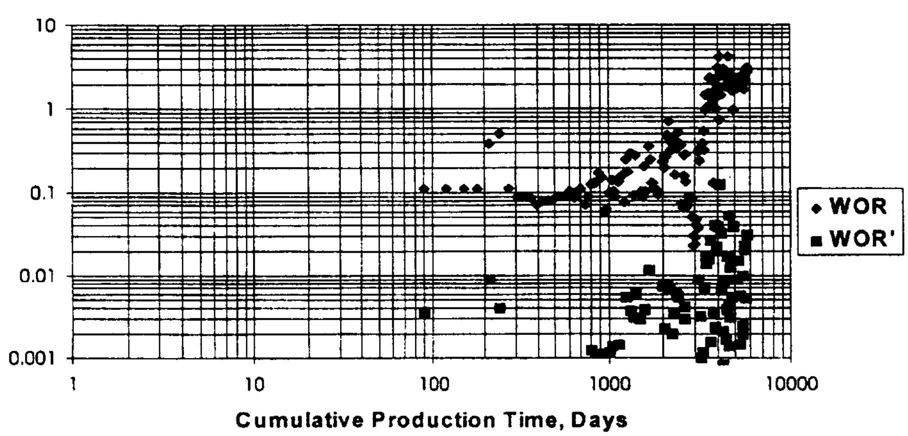

Figure 10 - Layer Break Through in a Producer

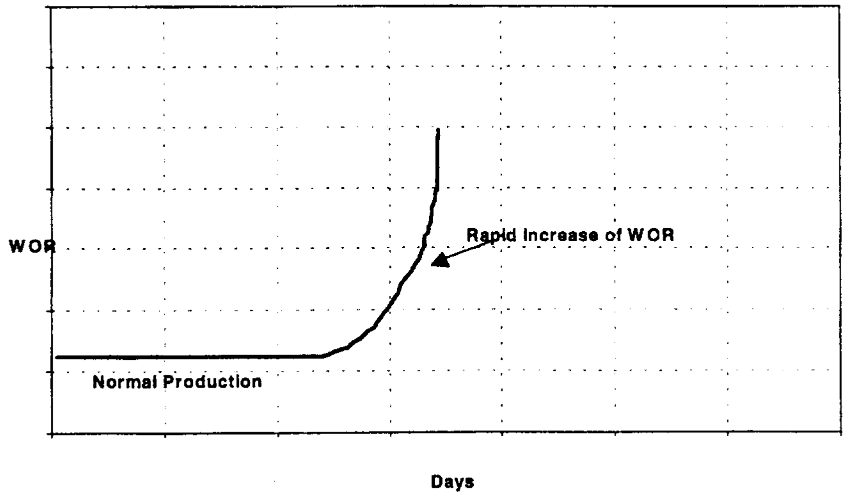

Figure 11 - Rapid Channeling Diagnostic Plot Example

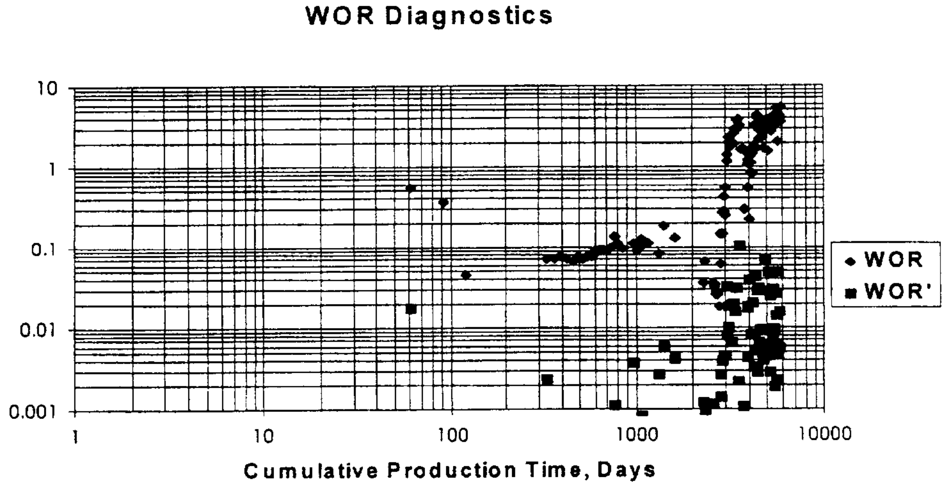

Figure 12 - Rapid Channeling in a Producer

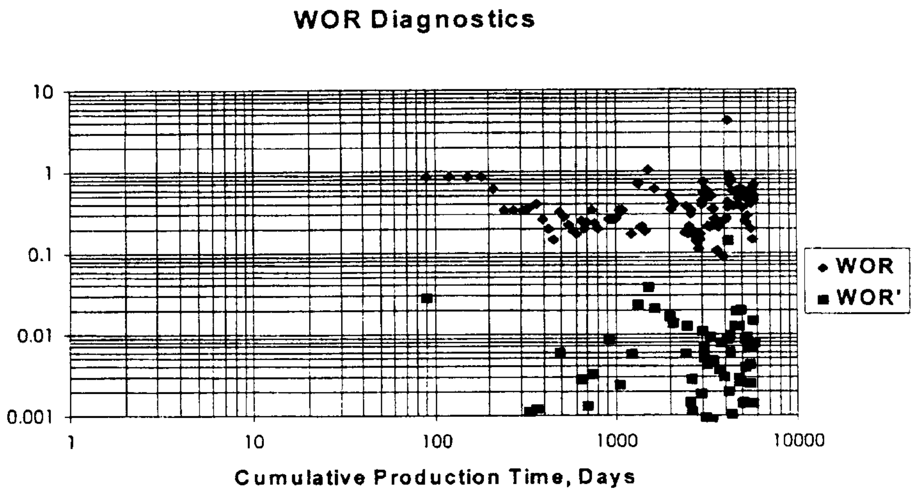

Figure 13 - Producer with No Response

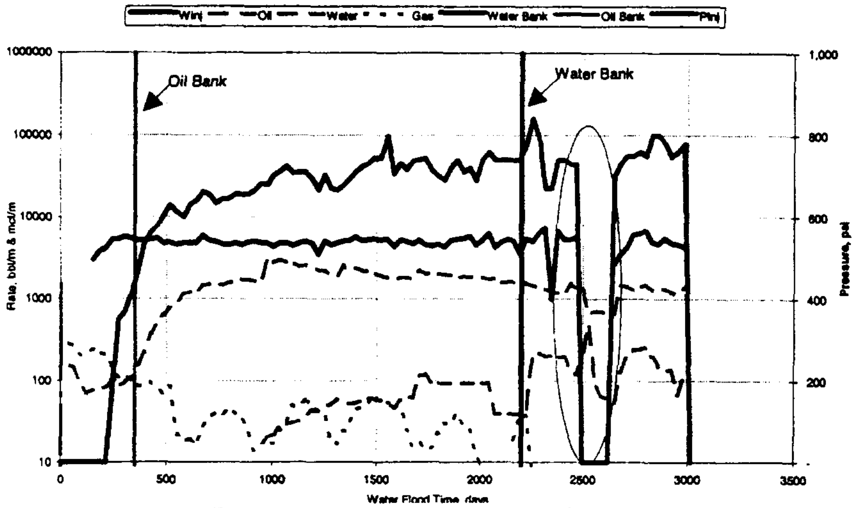

Figure 14 - Injector - Producer Overlay

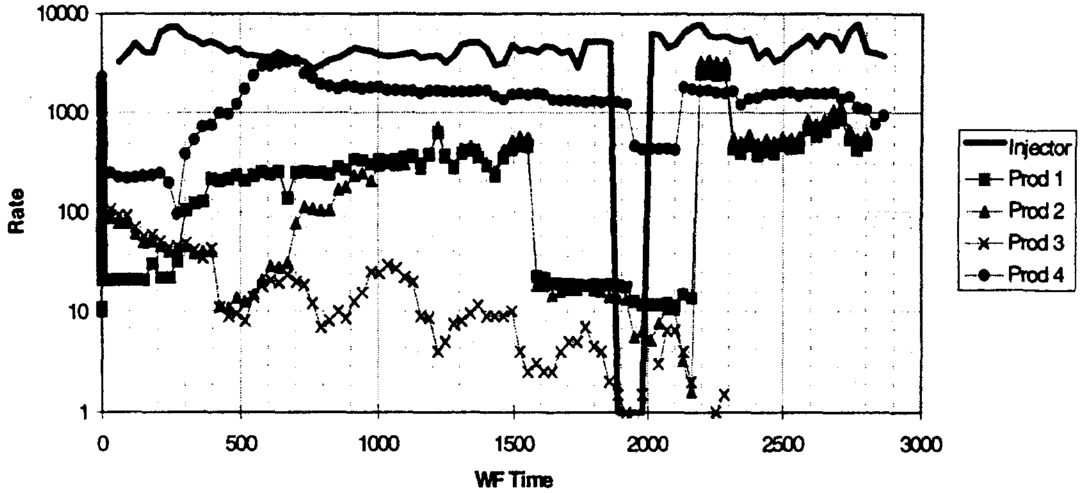

Figure 15 - Injector - Multiple Producer Overlay

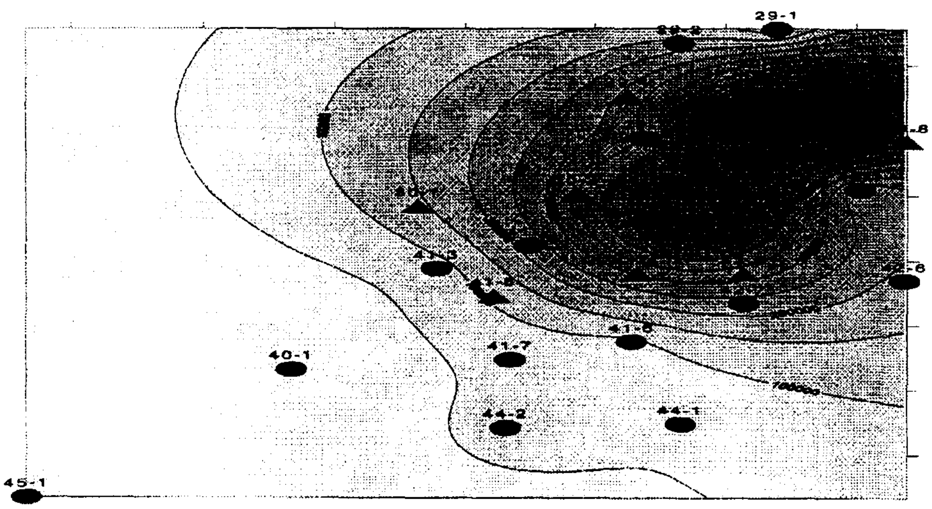

Figure 16 - Gas Cumulative Map

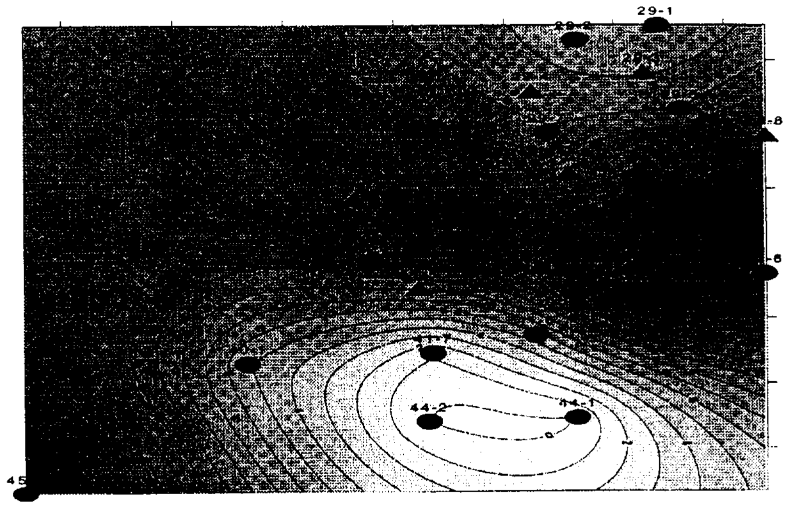

Figure 17 - Gas Rate Map

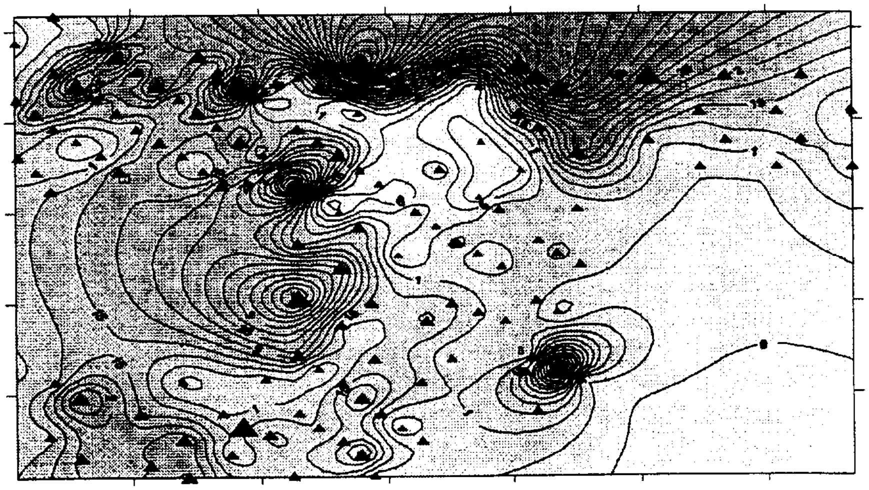

Figure 18 - kh Reservoir Proprieties Map

Figure 19 - Oil Rate Map

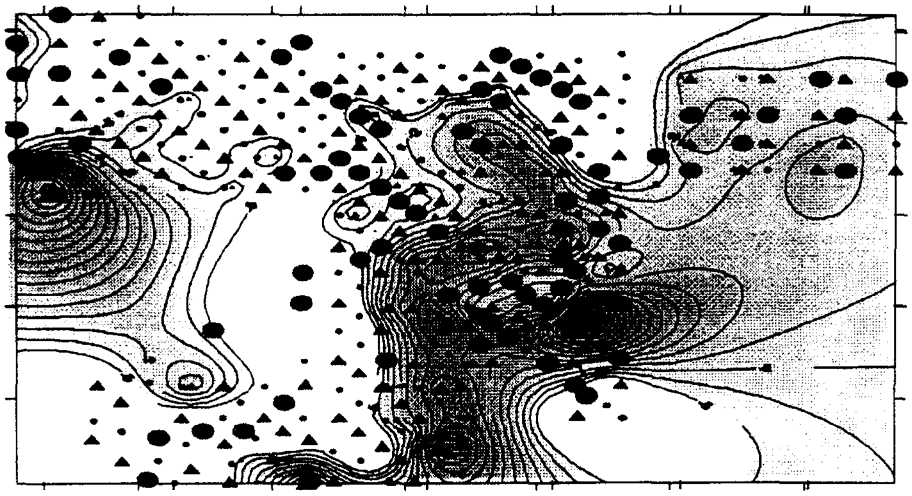

Figure 20 - Positive Net-Out

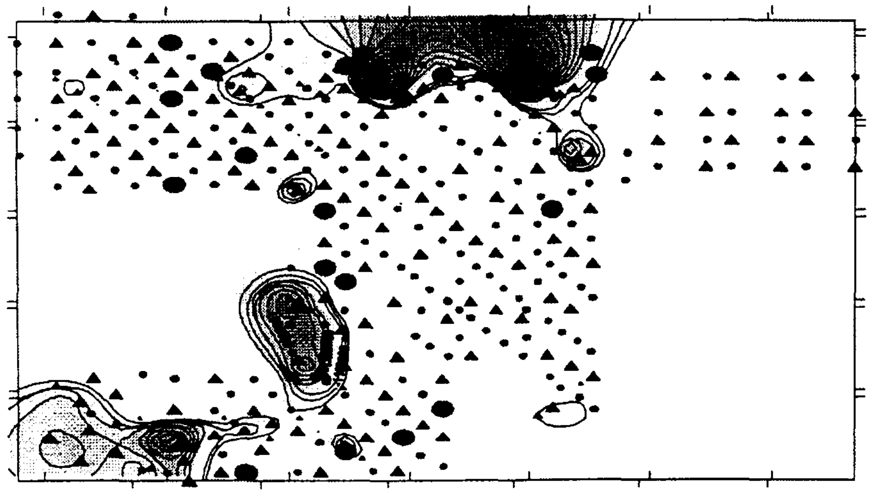

Figure 21 - Negative Net-Out

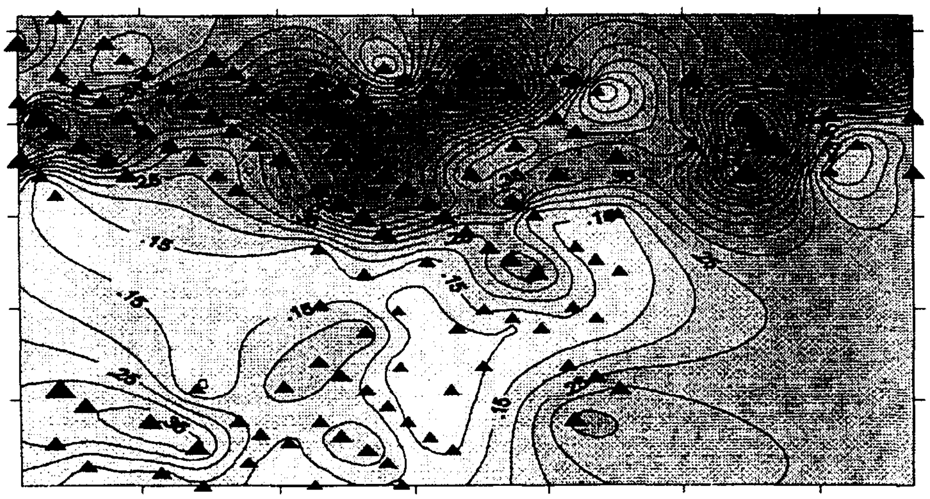

Figure 22 - Oil Cut Map

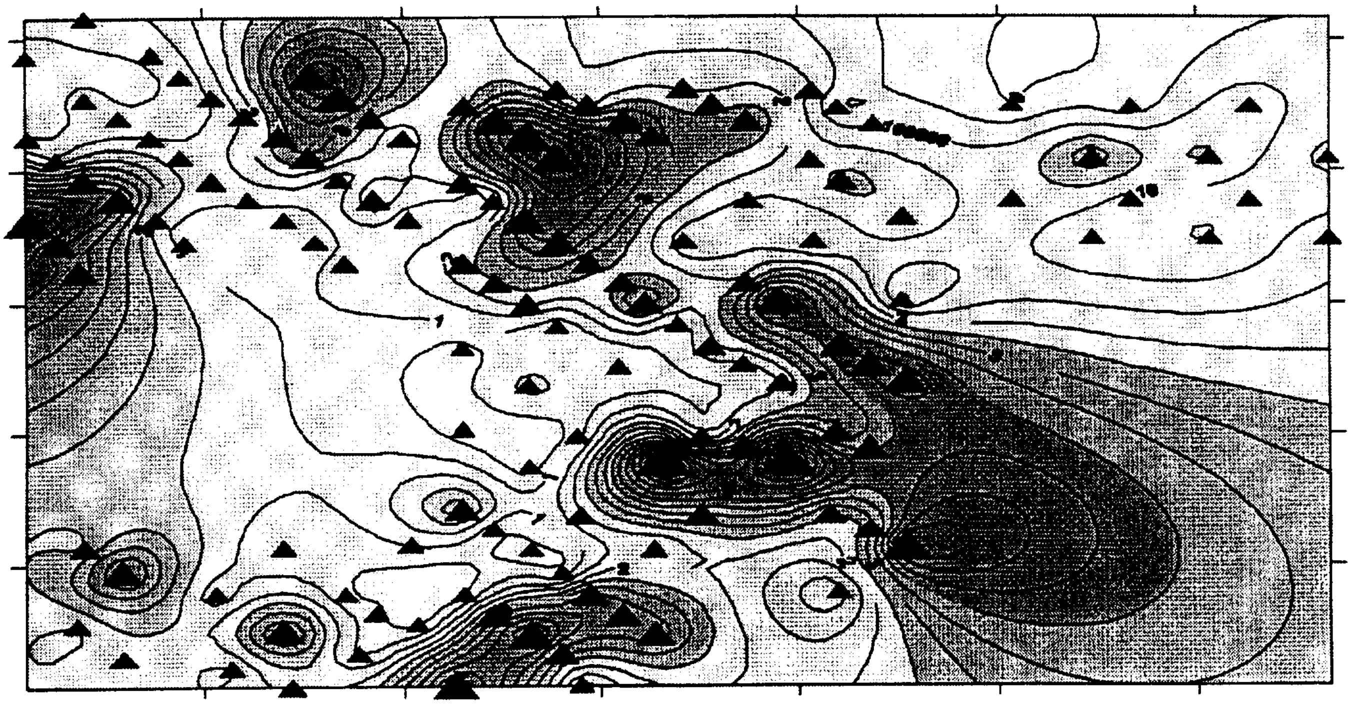

Figure 23 - Remaining Reserves Map

Figure 24 - Reservoir Pressure